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# NONTRADED GOODS, MARKET SEGMENTATION, AND EXCHANGE RATES

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# Nontraded Goods, Market Segmentation, and Exchange Rates*

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**Abstract**

Empirical evidence suggests that movements in international relative prices (such as the real exchange rate) are large and persistent. Nontraded goods, both in the form of final consumption goods and as an input into the production of final tradable goods, are an important aspect behind international relative price movements. In this paper we show that nontraded goods have important implications for exchange rate behavior, even though fluctuations in the relative price of nontraded goods account for a relatively small fraction of real exchange rate movements. In our quantitative study nontraded goods magnify the volatility of exchange rates when compared to the model without nontraded goods. Cross-country correlations and the correlation of exchange rates with other macro variables are closer in line with the data. In addition, contrary to a large literature, standard alternative assumptions about the currency in which firms price their goods are virtually inconsequential for the properties of aggregate variables in our model, other than the terms of trade.

**Keywords:** exchange rates; nontraded goods; incomplete asset markets.
**JEL classification:** F3, F41

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# 1 Introduction

Empirical evidence regarding international relative prices at the consumer level suggests that arbitrage in international markets is not rapid and that these markets are highly segmented. In fact, even markets for traded goods appear to be highly segmented internationally: In the data, both real exchange rate movements and deviations from the law of one price for traded goods are large and persistent. Nontraded goods, in the form of final consumption goods and as an input into the production of final tradable goods, are an important aspect behind international relative price differentials for at least three reasons. First, international price differentials for these goods are not subject to arbitrage. Second, nontraded goods represent a large proportion of GDP. In the United States, for instance, consumption of nontraded goods represents about 40 percent of GDP and retail services represents about 20 percent.[1] Third, empirical evidence suggests that the degree of tradability of the inputs of a good plays an important role in accounting for its relative price differentials across countries.[2]

In this paper we show that nontraded goods (in final consumption and in retail services) play an important role in exchange rate behavior in the context of an otherwise standard open-economy macro model. In our model, nontraded goods have an important role even though fluctuations in the relative price of nontraded goods account for a small proportion of real exchange rate fluctuations.[3] Our quantitative study with nontraded goods generates implications along several dimensions that are more closely in line with the data relative to the model that abstracts from nontraded goods. In addition, contrary to a large literature, standard alternative assumptions about the currency in which firms price their goods are virtually inconsequential for the properties of aggregate variables in our model, other than the terms of trade.

[1]These numbers are computed as the average share of personal consumption of services in private GDP from 1973 to 2004 and the average share of wholesale and retail services and transportation in private GDP from 1987 to 1997. The dichotomy between traded and nontraded goods is not, of course, a clear one. Here we adopt a conventional dichotomy that associates services with nontraded goods.

[2]See, for instance, the findings in Crucini, Telmer, and Zachariadis (2005).

[3]Decompositions of U.S. real exchange rate fluctuations into movements in the relative price of tradable goods across countries and movements in the relative price of nontraded goods to tradable goods have typically uncovered a small role for the nontraded component (see Engel, 1999). Betts and Kehoe (2004) and Burstein, Eichenbaum, and Rebelo (2005) argue that movements in the relative price of nontraded goods play a larger role in explaining U.S. real exchange rate fluctuations when tradable goods prices are not measured using retail prices.

We build a two-country general equilibrium model of exchange rates that features two roles for nontraded goods: as final consumption and as an input into the production of final tradable goods (retail services). In addition to retail services, final tradable goods require the use of local and imported intermediate traded inputs. Intermediate traded goods and nontraded goods are produced using local labor and capital services. Thus, our model has an input-output structure (as in Obstfeld, 2001), where the output of some sectors is used as an input to the production of final goods. In addition to intermediate goods, agents in the two countries also trade one riskless nominal bond. We calibrate the model to match, among other targets, the shares of retail services, nontraded consumption goods, and trade in GDP to observed U.S. averages.

The presence of nontraded goods in our model increases the relative volatility of nominal and real exchange rates relative to the volatility in the model without nontraded goods. An important aspect of the behavior of exchange rates in our model with nontraded goods hinges on the agent's inability to optimally share the risk associated with country-specific shocks to productivity in the nontraded goods sector. In response to a (persistent) positive shock to productivity in this sector, agents wish to consume and invest more. However, higher consumption and investment of tradable goods requires the use (in fixed proportions) of both traded intermediate inputs and nontraded inputs. The nominal exchange rate and the terms of trade of the home country depreciate sharply in response to this shock, ensuring a substitution effect toward domestic inputs and away from imported inputs.[4] Notice that, with nominal price rigidities, the response of the nominal exchange rate to a productivity shock in the nontraded goods sector generates a large fluctuation in the international relative price of final tradable goods and the real exchange rate. That is, nontraded goods play an important role in accounting for fluctuations in international relative prices in our model even though, as in the data, fluctuations in the relative price of these goods account for a small proportion of real exchange rate fluctuations. In addition, the presence of nontraded goods in our model also generates cross-country correlations and a correlation of the real exchange rate with other variables that are closer in line with the data.

[4]In an optimal risk sharing environment, the foreign agent produces relatively more traded inputs and the nominal exchange rate does not depreciate as much in response to this shock.

The discussion of the properties of relative international prices has been closely tied with a discussion on the nature of the pricing decisions by firms.[5] The observed slow pass-through of exchange rate changes to consumer prices and deviations from the law of one price for traded goods are consistent with prices of imported goods that are sticky in the currency of the consumer (local currency pricing). This pricing mechanism, however, dampens the expenditure-switching effect of nominal exchange rate movements. This effect, a central feature of models in which imports are priced in the currency of the seller (producer currency pricing), is consistent with empirical evidence suggesting that exchange rate movements are positively correlated with a country's terms of trade.[6] Our setup allows us to disentangle the implications of these two alternative pricing mechanisms that are standard in the open-economy macro literature. In our model, different assumptions regarding the pricing decisions of firms are virtually inconsequential for the properties of aggregate variables, other than the terms of trade. In particular, the real exchange rate and the international relative price of final tradable goods behave similarly across the two price setting regimes. This result follows from the fact that trade represents a relatively small fraction of GDP and that the behavior of the nominal exchange rate is close to a random walk. The two pricing assumptions differ with respect to the correlations of the terms of trade and price of imports with other variables in the model. In particular, the terms of trade have a higher positive correlation with exchange rates under producer currency pricing than with local currency pricing. This higher positive correlation under producer currency pricing is closer in line with the correlation observed in the data.

Our paper is related to recent quantitative studies of exchange rate behavior. Corsetti, Dedola, and Leduc (2004a) explore the role of (nontraded) distribution services in explaining the negative correlation between real exchange rates and relative consumption across countries, and Corsetti, Dedola, and Leduc (2004b) examine the behavior of pass-through in a model that includes distribution services. These two papers explore the implications of the lower price elasticity of traded inputs brought about by the location of distribution services in the production chain. In contrast, in our framework, the price elasticity of traded inputs

[5]See, for instance, Engel (2002), Obstfeld (2001), Obstfeld and Rogoff (2000a), and the references therein.
[6]See Obstfeld and Rogoff (2000b).

is not affected by retail services. Our paper is also related to the work of Chari, Kehoe, and McGrattan (2002), who assume that all goods are traded and explore the interaction between local currency pricing and monetary shocks in explaining real exchange rate behavior. Our study is in the general methodological spirit of theirs, but highlights the importance of nontraded goods in accounting for exchange rate behavior.

The paper is organized as follows. In Section 2 we describe the model and in Section 3 we discuss the calibration. In Section 4 we present the results and discuss the role of nontraded goods in our model. In Section 5 we consider the implications of alternative price setting mechanisms and we conclude in Section 6.

# 2 The Model

The world economy consists of two countries, denominated home and foreign. Each country is populated by a continuum of identical households, firms, and a monetary authority. Households consume two types of final goods, a tradable good $T$ and a nontraded good $N$. The production of nontraded goods requires capital and labor, and the production of tradable consumption goods requires the use of home and foreign traded inputs as well as nontraded goods. Therefore, consumer markets of tradable consumption goods are segmented, and consumers are unable to arbitrage price differentials for these goods across countries.

Households own the capital stock and rent labor and capital services to firms. Households also hold domestic currency and trade a riskless bond denominated in home currency with foreign households. Each firm is a monopolistic supplier of a differentiated variety of a good and sets the price for the good it produces in a staggered fashion.

In what follows, we describe the home country economy. The foreign country economy is analogous. Asterisks denote foreign country variables.

## 2.1 Households

The representative consumer in the home country maximizes the expected value of lifetime utility, given by

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, h_t, \frac{M_{t+1}}{P_t}\right), \tag{1}$$

where $c_t$ denotes consumption of a composite good to be defined below, $h_t$ denotes hours worked, $M_{t+1}/P_t$ denotes real money balances held from period $t$ to period $t+1$, and $u$ represents the momentary utility function.

The composite good $c_t$ is an aggregate of consumption of a tradable good $c_{T,t}$ and a nontraded good $c_{N,t}$, and is given by

$$c_t = \left(\omega_T^{\frac{1}{\gamma}} c_{T,t}^{\frac{\gamma-1}{\gamma}} + (1-\omega_T)^{\frac{1}{\gamma}} c_{N,t}^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \gamma > 0.$$

The parameter $\omega_T$ determines the agent's bias toward the tradable good, and the elasticity of substitution between tradable and nontraded goods is given by $\gamma$.

Consumption of the tradable and nontraded good is a Dixit-Stiglitz aggregate of the quantity consumed of all the varieties of each good:

$$c_j = \left(\int_0^1 \left(c_j(i)\right)^{\frac{\gamma_j-1}{\gamma_j}} di\right)^{\frac{\gamma_j}{\gamma_j-1}}, \quad j = T, N, \tag{2}$$

where $\gamma_j$ is the elasticity of substitution between any two varieties of good $j$. Given home-currency prices of the individual varieties of tradable and nontraded goods, $P_{T,t}(i)$ and $P_{N,t}(i)$, the demand functions for each individual variety of tradable and nontraded goods, $c_{T,t}(i)$ and $c_{N,t}(i)$, and the consumption-based price of one unit of the tradable and nontraded good, $P_{T,t}$ and $P_{N,t}$, are obtained by solving a standard expenditure minimization problem subject to (2).[7]

The representative consumer in the home country owns the capital stock $k_t$, holds domestic currency, and trades a riskless bond denominated in home-currency units with the foreign representative consumer. We denote by $B_{t-1}$ the stock of bonds held by the household at

[7] See, for example, Obstfeld and Rogoff (1996), Chapter 10.

the beginning of period $t$. These bonds pay the gross nominal interest rate $R_{t-1}$. There is a cost of holding bonds given by $\Phi_b(B_{t-1}/P_t)$, where $\Phi_b(\cdot)$ is a convex function.[8] The consumer rents labor services $h_t$ and capital services $k_t$ to domestic firms at rates $w_t$ and $r_t$, respectively, both expressed in units of final goods. Finally, households receive nominal dividends $D_t$ from domestic firms and transfers $T_t$ from the monetary authority.

The intertemporal budget constraint of the representative consumer, expressed in home-currency units, is given by

$$P_t c_t + P_{T,t} i_t + M_{t+1} + B_t + P_t \Phi_b\left(\frac{B_{t-1}}{P_t}\right) \leq P_t\left(w_t h_t + r_t k_t\right) + R_{t-1}B_{t-1} + D_t + M_t + T_t. \quad (3)$$

Note that we assume that investment $i_t$ is carried out in final tradable goods.[9] The law of motion for capital accumulation is

$$k_{t+1} = k_t(1-\delta) + k_t \Phi_k\left(\frac{i_t}{k_t}\right), \quad (4)$$

where $\delta$ is the depreciation rate of capital and $\Phi_k(\cdot)$ is a convex function representing capital adjustment costs.[10]

Households choose sequences of consumption, hours worked, investment, money holdings, debt holdings, and capital stock to maximize the expected discounted lifetime utility (1) subject to the sequence of budget constraints (3) and laws of motion of capital (4).

## 2.2 Production

In this paper we consider two distinct uses for nontraded goods: as final consumption and as an input into the production of final tradable consumption goods. To this end, there are three sectors of production in our model: the nontraded goods sector, the intermediate traded goods sector, and the final tradable goods sector. In each sector firms produce a

[8]This cost of holding bonds guarantees that the equilibrium dynamics of our model are stationary. See Schmitt-Grohé and Uribe (2003) for a discussion and alternative approaches.

[9]This assumption is consistent with empirical evidence suggesting that investment has a substantial nontraded component and import content. See, for instance, Burstein, Neves, and Rebelo (2004).

[10]Capital adjustment costs are incorporated to reduce the response of investment to country-specific shocks. In their absence the model would imply excessive investment volatility. See, for instance, Baxter and Crucini (1995).

continuum of differentiated varieties. We now describe each sector.

### 2.2.1 Final Tradable Goods Sector

There is a continuum of firms in the final tradable goods sector, each producing a differentiated variety $y_T(i)$, $i \in [0, 1]$. Each firm combines a composite of home and foreign tradable intermediate inputs $X_T$ with a composite of nontraded goods $X_N$. The production function of each of these firms is

$$y_{T,t}(i) = \left(\omega^{\frac{1}{\rho}} X_{N,t}(i)^{\frac{\rho-1}{\rho}} + (1-\omega)^{\frac{1}{\rho}} X_{T,t}(i)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \quad \rho > 0, \tag{5}$$

where $\rho$ denotes the elasticity of substitution between $X_{T,t}(i)$ and $X_{N,t}(i)$ and $\omega$ is a weight. We interpret this sector as a retail sector. Thus, $X_{N,t}(i)$ can be interpreted as retail services used by firm $i$.

For simplicity, we assume that the local nontraded good used for retail services $X_{N,t}$ is given by the same Dixit-Stiglitz aggregator (2) as the nontraded consumption good $c_N$. Thus, $P_{N,t}$ is the price of one unit of $X_{N,t}$. The composite of home and foreign intermediate tradable inputs $X_{T,t}$ is given by

$$X_{T,t} = \left[\omega_X^{\frac{1}{\xi}} X_{h,t}^{\frac{\xi-1}{\xi}} + (1-\omega_X)^{\frac{1}{\xi}} X_{f,t}^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi}{\xi-1}}, \tag{6}$$

where $X_{h,t}$ and $X_{f,t}$ denote home and foreign intermediate traded goods, respectively. These goods $X_h$ and $X_f$ are each a Dixit-Stiglitz aggregate, as in (2), of all the varieties of each good produced in the home and foreign intermediate traded goods sector, $X_h(j)$ and $X_f(j)$, $j \in [0, 1]$. The parameter $\xi$ denotes the elasticity of substitution between home and foreign intermediate inputs and the weight $\omega_X$ determines the bias toward the local traded input.

In our setup, each firm in the retail sector combines retail services $X_N$ with a bundle of local and imported intermediate inputs $X_T$. Alternatively, firms in the retail sector could incur distribution costs with each intermediate input (local and imported), prior to combining them into a final composite tradable good, as in Corsetti and Dedola (2005). Note that in this alternative specification, distribution costs lower the price elasticity of intermediate inputs, while in our model they do not. We believe our equations (5) and (6) represent a reasonable specification of the production process for two reasons. First, a large fraction of U.S. trade consists of intermediate inputs that enter into the production of other goods and that do not require a lot of wholesale or retail trade. Second, retail trade is the largest component of distribution services in value added.[11]

Let the unit price (in home-currency units) of $X_{h,t}$ and $X_{f,t}$ be denoted by $P_{h,t}$ and $P_{f,t}$, respectively. Then, the price of one unit of the composite tradable good $X_{T,t}$ is given by

$$P_{X,t} = \left[\omega_X P_{h,t}^{1-\xi} + (1-\omega_X) P_{f,t}^{1-\xi}\right]^{\frac{1}{1-\xi}}. \tag{7}$$

Given these prices, the real marginal cost of production, common to all firms in this sector, is $\psi_T$,

$$\psi_{T,t} = \left[\omega \left(\frac{P_{X_N,t}}{P_t}\right)^{1-\rho} + (1-\omega)\left(\frac{P_{X_T,t}}{P_t}\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{8}$$

Firms in this sector set prices for $J_T$ periods in a staggered way. That is, each period, a fraction $1/J_T$ of these firms optimally chooses prices that are set for $J_T$ periods. The problem of a firm $i$ adjusting its price in period $t$ is given by

$$\max_{P_{T,t}(0)} \sum_{i=0}^{J_T-1} E_t\left[\vartheta_{t+i|t}\left(P_{T,t}(0) - P_{t+i}\psi_{T,t+i}\right) y_{T,t+i}(i)\right],$$

where $y_{T,t+i}(i) = c_{T,t+i}(i) + i_{t+i}(i)$ represents the demand (for consumption and investment purposes) faced by this firm in period $t+i$. The term $\vartheta_{t+i|t}$ denotes the pricing kernel, used to value profits at date $t+i$, which are random as of $t$. In equilibrium $\vartheta_{t+i|t}$ is given by the consumer's intertemporal marginal rate of substitution in consumption, $\beta^i(u_{c,t+i}/u_{c,t})P_t/P_{t+i}$.

### 2.2.2 Intermediate Traded Goods Sector

There is a continuum of firms in the intermediate traded goods sector, each producing a differentiated variety of the intermediate traded input, $X_h(i)$, $i \in [0,1]$, which are used by

[11] Recall that the retail sector includes firms engaged in the final step in the distribution of merchandise for personal consumption (final traded goods in our model).

local and foreign firms in the retail sector. The production of each intermediate traded input requires the use of capital and labor. The production function is $y_{h,t}(i) = z_{h,t}k_{h,t}(i)^{\alpha}l_{h,t}(i)^{1-\alpha}$. The term $z_{h,t}$ represents a productivity shock specific to this sector, and $k_{h,t}$ and $l_{h,t}$ denote the use of capital and labor services by firm $i$. Each firm chooses one price, denominated in units of domestic currency, for the home and foreign markets.[12] Thus, the law of one price holds for intermediate traded inputs.[13]

Like retailers, intermediate goods firms set prices in a staggered fashion. The problem of an intermediate goods firm in the traded sector setting its price in period $t$ is described by

$$\max_{P_{h,t}(0)} \sum_{i=0}^{J_h-1} E_t \left[\vartheta_{t+i|t} \left(P_{h,t}(0) - P_{t+i}\psi_{h,t+i}\right) \left(X_{h,t+i}(i) + X^*_{h,t+i}(i)\right)\right], \tag{9}$$

where $X_{h,t+i}(i) + X^*_{h,t+i}(i)$ denotes total demand (from home and foreign markets) faced by this firm in period $t+i$. The term $\psi_h$ denotes the real marginal cost of production (common to all firms in this sector) and is given by

$$\psi_{h,t} = \frac{1}{z_{h,t}} \left(\frac{r_t}{\alpha}\right)^{\alpha} \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}. \tag{10}$$

#### 2.2.3 Nontraded Goods Sector

This sector has a structure analogous to the intermediate traded sector. Each firm operates the production function $y_{N,t}(i) = z_{N,t}k_{N,t}(i)^{\alpha}l_{N,t}(i)^{1-\alpha}$, where all the variables have analogous

[12] Note that, differently from Corsetti and Dedola (2005), in our setup the presence of distribution services does not generate an incentive for intermediate traded goods firms to price discriminate across countries. This difference between the two models arises from the different location of distribution services in the production chain.

[13] Therefore, in our benchmark model, the pass-through of exchange rate changes to import prices at the wholesale level is one. Our benchmark pricing assumption makes our model consistent with the finding that the exchange rate pass-through is higher at the wholesale than at the retail level. Empirical evidence, however, suggests that exchange rate pass-through is lower than one even at the wholesale level (for instance, Goldberg and Knetter, 1997). In Section 5 we show that an alternative pricing assumption for intermediate goods producers, which is consistent with a lower exchange rate pass-through at the wholesale level, is virtually inconsequential for the properties of aggregate variables in our model, other than the terms of trade.

interpretations. The price-setting problem for a firm in this sector is

$$\max_{P_{N,t}(0)} \sum_{i=0}^{J_N-1} E_t \left[ \vartheta_{t+i|t} \left( P_{N,t}(0) - P_{t+i}\psi_{N,t+i} \right) y_{N,t+i}(i) \right],$$

where $y_{N,t+i}(i) = X_{N,t+i}(i) + c_{N,t+i}(i)$ denotes demand (from the retail sector and consumers) faced by this firm in period $t+i$. The real marginal cost of production in this sector is given by $\psi_{N,t} = \psi_{h,t} z_{h,t}/z_{N,t}$.

## 2.3 The Monetary Authority

The monetary authority issues domestic currency. Additions to the money stock are distributed to consumers through lump-sum transfers $T_t = M_t^s - M_{t-1}^s$.

The monetary authority is assumed to follow an interest rate rule similar to those studied in the literature. In particular, the interest rate is given by

$$R_t = \rho_R R_{t-1} + (1-\rho_R) \left[ \bar{R} + \rho_{R,\pi} \left( E_t \pi_{t+1} - \bar{\pi} \right) + \rho_{R,y} \ln \left( y_t/\bar{y} \right) \right], \tag{11}$$

where $\pi_t$ denotes CPI-inflation, $y_t$ denotes real GDP, and barred variables represent their target value.[14]

## 2.4 Market Clearing Conditions and Model Solution

We close the model by imposing market clearing conditions for labor, capital, and bonds,

$$\begin{aligned} h_t &= \sum_{i=0}^{J_h-1} l_{h,t}(i) + \sum_{i=0}^{J_N-1} l_{N,t}(i), \\ k_t &= \sum_{i=0}^{J_h-1} k_{h,t}(i) + \sum_{i=0}^{J_N-1} k_{N,t}(i), \\ 0 &= B_t + B_t^*. \end{aligned}$$

We focus on the symmetric and stationary equilibrium of the model. We solve the model

[14] We do not include a stochastic component to monetary policy. Our results are not affected by introducing calibrated shocks to the interest rate rule.

by linearizing the equations characterizing equilibrium around the steady-state and solving numerically the resulting system of linear difference equations.

We now define some variables of interest. The real exchange rate $q$, defined as the relative price of the reference basket of goods across countries, is given by $q = eP^*/P$, where $e$ denotes the nominal exchange rate. The terms of trade $\tau$ represent the relative price of imports in terms of exports in the home country and are given by $\tau = P_f/(eP_h^*)$. Nominal GDP in the home country is given by $Y = Pc + P_T i + NX$, where $NX = eP_h^* X_h^* - P_f X_f$ represents nominal net exports. We obtain real GDP by constructing a chain-weighted index as in the National Income and Product Accounts.

# 3 Calibration

In this section we report the parameter values used in solving the model. Our benchmark calibration assumes that the world economy is symmetric so that the two countries share the same structure and parameter values. The model is calibrated largely using U.S. data as well as productivity data from the OECD STAN database. We assume that a period in our model corresponds to one quarter. Our benchmark calibration is summarized in Table 1.

## 3.1 Preferences and Production

We assume a momentary utility function of the form

$$u\left(c, h, \frac{M}{P}\right) = \frac{1}{1-\sigma}\left\{\left(ac^{\eta} + (1-a)\left(\frac{M}{P}\right)^{\eta}\right)^{\frac{1-\sigma}{\eta}} \exp\left\{-v(h)(1-\sigma)\right\} - 1\right\}. \tag{12}$$

The discount factor $\beta$ is set to 0.99, implying a 4 percent annual real rate in the stationary economy. We set the curvature parameter $\sigma$ equal to two.

The parameters $a$ and $\eta$ are obtained from estimating the money demand equation implied by the first-order condition for bond and money holdings. Using the utility function defined above, this equation can be written as

$$\log \frac{M_t}{P_t} = \frac{1}{\eta - 1} \log \frac{a}{1-a} + \log c_t + \frac{1}{\eta - 1} \log \frac{R_t - 1}{R_t}. \tag{13}$$

We use data on $M1$, the three-month interest rate on T-bills, consumption of nondurables and services, and the price index is the deflator on personal consumption expenditures. The sample period is 1959:1-2004:3. The parameter estimation is carried out in two steps. Because real $M1$ is nonstationary and not co-integrated with consumption, equation (13) is first differenced. The coefficient estimate on consumption is 0.975 and is not statistically different from one, so the assumption of a unitary consumption elasticity implied by the utility function is consistent with the data. The coefficient on the interest rate term is $-0.021$, and we calibrate $\eta$ to be $-32$, which implies an interest elasticity of $-0.03$. Next, we form a residual $u_t = \log(M_t/P_t) - \log c_t - \frac{1}{\eta-1}\log\frac{R_t-1}{R_t}$. This residual is a random walk with drift, and we use a Kalman filter to estimate the drift term, which is the constant in equation (13). The resulting estimate of $a$ is very close to one, and we set $a$ equal to 0.99.[15] Therefore, our calibration is close to imposing separability between consumption and real money balances.

Labor disutility is assumed to take the form

$$v(h) = \frac{\psi_0}{1+\psi_1} h^{1+\psi_1}.$$

The parameters $\psi_0$ and $\psi_1$ are set to 3.47 and 0.15, respectively, so that the fraction of working time in steady-state is 0.25 and the elasticity of labor supply, with marginal utility of consumption held constant, is 2. This elasticity is consistent with estimates in Mulligan (1998) and Solon, Barsky, and Parker (1994).

The elasticity of substitution between tradable and nontraded goods in consumption, $\gamma$, is set to 0.74 following Mendoza's (1995) estimate for a sample of industrialized countries. We assume that retail services and traded inputs exhibit very low substitutability in the production of final tradable goods and are used in fixed proportions. Thus we set the elasticity of substitution $\rho$ to 0.001. There is considerable uncertainty regarding estimates of the elasticity of substitution between domestic and imported goods, $\xi$. In addition, this parameter has been shown to play a crucial role in key business cycle properties of two-

[15]The estimation procedure neglects sampling error, because in the second stage we are treating $\eta$ as a parameter rather than as an estimate.

country models.[16] A reference estimate of this elasticity for the U.S. has been 1.5 from Whalley (1985). Hooper, Johnson, and Marquez (1998) estimate import and export price elasticities for G-7 countries and report elasticities for the U.S. between 0.3 and 1.5. We set this elasticity to the mid-point in this range (0.85).

We choose the weights on consumption of tradable goods $\omega_T$, on nontraded retail services $\omega$, and on domestic traded inputs $\omega_X$ to simultaneously match, given all other parameter choices, the share of consumption of nontraded goods in GDP, the share of retail services in GDP, and the average share of imports in GDP.[17] Over the period 1973-2004, these shares in the U.S. averaged 0.44, 0.19, and 0.13, respectively. For our benchmark model, we obtained $\omega_T = 0.44$, $\omega = 0.38$, and $\omega_X = 0.59$. Given these parameter choices, the model implies a share of nontraded consumption in total consumption of 0.55, which is consistent with the data (see, for instance, Stockman and Tesar, 1995).

We set the elasticity of substitution between varieties of a given good, $\gamma_j$, equal to 10, for all goods $j = T, N, h$. As usual, this elasticity is related to the markup chosen when firms adjust their prices, which is $\gamma_j / (\gamma_j - 1)$. Our choice for $\gamma_j$ implies a markup of 1.11, which is consistent with the empirical work of Basu and Fernald (1997). In our benchmark calibration, we assume that all firms set prices for four quarters ($J_j = 4$).

Regarding production, we take the standard value of $\alpha = 1/3$, implying that one-third of payments to factors of production goes to capital services.

## 3.2 Monetary Policy Rule

The parameters of the nominal interest rate rule are taken from the estimates in Clarida, Galí, and Gertler (1998) for the United States. We set $\rho_R = 0.9$, $\alpha_{p,R} = 1.8$, and $\alpha_{y,R} = 0.07$. The target values for $R$, $\pi$, and $y$ are their steady-state values, and we have assumed a steady-state inflation rate of 2 percent per year.

[16] See, for example, Corsetti, Dedola, and Leduc (2004a) and Heathcote and Perri (2002).

[17] By retail services we mean the value added from retail trade, wholesale trade, and transportation excluding transit and ground transportation services. Other expenses that are not included in our measure and that affect the cost of bringing goods to market include information acquisition, marketing, and currency conversion, to name a few. We, therefore, believe our calibration leans on the conservative side.

## 3.3 Capital Adjustment and Bond Holding Costs

We model capital adjustment costs as an increasing convex function of the investment to capital stock ratio. Specifically, $\Phi_k(i/k) = \phi_0 + \phi_1(i/k)^{\phi_2}$. We parameterize this function so that $\Phi_k(\delta) = \delta$, $\Phi_k^{'}(\delta) = 1$, and the volatility of HP-filtered consumption relative to that of HP-filtered GDP is approximately 0.64, as in the U.S. data.

The bond holdings cost function is $\Phi_b\left(B_t/P_t\right) = \theta_b\left(B_t/P_t\right)^2/2$, as in Neumeyer and Perri (2005). The parameter $\theta_b$ is set to 0.001, the lowest value that guarantees that the solution of the model is stationary, without affecting the short-run properties of the model.

## 3.4 Productivity Shocks

The technology shocks are assumed to follow independent $AR(1)$ processes $z_{i,t}^k = Az_{i,t-1}^k + \varepsilon_{i,t}^k$, where $i = \{U.S., ROW\}$ and $k = \{mf, sv\}$; $ROW$ stands for rest of world, $mf$ for manufacturing and $sv$ for services. $\varepsilon_{i,}^k$ represents the innovation to $z_i^k$ and has standard deviation $\sigma_i^k$. The data are taken from the OECD STAN data set on total factor productivity (TFP) for manufacturing and for wholesale and retail services.[18] The data are annual and run from 1971-1993, making for a very short sample in which to infer the time series characteristics of these measures. We cannot reject a unit root for any of the series, which is consistent with other data series on productivity in manufacturing, namely that constructed by the BLS or Basu, Fernald, and Kimball (2004).

The shortness of the time series on TFP prevents us from estimating any richer characterization of TFP with any precision.[19] In looking at the univariate autoregressive estimates, we found coefficients ranging from 0.9 for U.S. manufacturing to 1.05 for rest of world services. Therefore, we use as a benchmark stationary but highly persistent processes for each of the technology shocks. Based on these simple regressions, we set $A = 0.98$, and we set the ratio of the standard deviations of innovations to TFP on manufacturing and services, $\sigma_{\varepsilon^{mf}}/\sigma_{\varepsilon^{sv}}$, to 2. We choose $\sigma_{\varepsilon^{mf}}$ and $\sigma_{\varepsilon^{sv}}$ to match the volatility of GDP.

[18]The $ROW$ aggregate comprises Canada, Japan, West Germany, and the United Kingdom.

[19]We estimated a VAR to investigate the relationship across the four TFP series. It was hard to make sense of the results. In this regard our results are similar to those of Baxter and Farr (2001), who analyze the relationship between total factor productivity in manufacturing between the U.S. and Canada.

Table 1: Calibration

| | |
|---|---|
| *Preferences* | |
| Coefficient of risk aversion ($\sigma$) | 2 |
| Elasticity of labor supply | 2 |
| Time spent working | 0.25 |
| Interest elasticity of money demand ($1/(\nu-1)$) | -0.03 |
| Weight on consumption ($a$) | 0.99 |
| *Aggregates* | |
| Elast. of substitution $C_N$ and $C_T$ ($\gamma$) | 0.74 |
| Elast. of substitution $X$ and $\Omega$ ($\rho$) | 0.001 |
| Elast. of substitution $X_h$ and $X_f$ ($\xi$) | 0.85 |
| Elast. of substitution individual varieties | 10 |
| Share of imports in GDP | 0.13 |
| Share of retail services in GDP | 0.19 |
| Share of $C_N$ in GDP | 0.44 |
| *Production and Adjustment Functions* | |
| Capital share ($\alpha$) | 1/3 |
| Price stickiness ($J$) | 4 |
| Depreciation rate ($\delta$) | 0.025 |
| Relative volatility of consumption | 0.64 |
| Bond holdings ($\theta_b$) | 0.001 |
| *Monetary Policy* | |
| Coeff. on lagged interest rate ($\rho_R$) | 0.9 |
| Coeff. on expected inflation ($\rho_{\pi,R}$) | 1.8 |
| Coeff. on output ($\rho_{y,R}$) | 0.07 |
| *Productivity Shocks* | |
| Autocorrelation coeff. ($A$) | 0.98 |
| Std. dev. of innovations to $z_T$&$z_N$ | 0.006 & 0.003 |

# 4 Findings

In this section we assess the role of nontraded goods in our model. We report HP-filtered population moments for our model under the benchmark and alternative parameterizations in Table 2.[20] In addition, we report statistics for HP-filtered data, which take the United States as the home country and a composite of its major trading partners as the foreign country for the period 1973:Q1−2004:Q3.[21] Except for net exports, the table reports the

[20]We thank Robert G. King for providing the algorithms that compute population moments.
[21]The data are described in the Appendix.

standard deviation of variables divided by that of GDP. Net exports is measured as the HP-filtered ratio of net exports to GDP, and the standard deviation reported in the table is the standard deviation of this ratio.

We find that the presence of nontraded goods has important implications for the business cycle properties of our model. To illustrate the role of these goods we report results for three different experiments: eliminating retail services, eliminating nontraded consumption goods, and eliminating all nontraded goods simultaneously. Note that the model is subject to shocks to productivity in the traded and nontraded goods sector in the first two experiments, while only shocks to traded productivity affect the economy in the third experiment.

Abstracting from nontraded consumption goods and retail services lowers the volatility of nominal and real exchange rates relative to GDP from 1.54 and 1.50 to 1.21 and 1.16. In addition, the presence of nontraded goods lowers the correlation between exchange rates and other macro variables: the cross-correlations of the real exchange rate with real GDP and the terms of trade falls from 0.64 and 0.99 to 0.47 and 0.62. The presence of nontraded goods also improves the cross-country correlations of output, consumption, and investment. Therefore, nontraded goods bring a standard two-country open economy model closer to the data along several dimensions. Finally, with nontraded goods, the asset structure of the model (that is, whether agents have access to a complete set of state-contingent assets to insure against country-specific risk) matters for the business cycle properties of the model, while in the absence of nontraded goods these properties are indistinguishable across the two asset structures. This result follows from the fact that in our model with only one riskless bond, agents cannot insure (almost) optimally against shocks to productivity in the nontraded goods sector.

## 4.1 The Benchmark Economy

The benchmark model implies that nominal and real exchange rates are about 1.5 times as volatile as real GDP. In our data, dollar nominal and real exchange rates are about 3.3 and 3.2 times as volatile as real GDP. The volatility of nominal and real exchange rates in our model is accounted for mostly by productivity shocks to the nontraded goods sector. Shocks to productivity in the traded goods sector imply minimal responses of exchange rates in the

Table 2: Model results

| Statistic | Data | Benchmark Economy | No Retail | No $C_{NT}$ | No NT | Complete Markets |
|---|---|---|---|---|---|---|
| *Stand. Dev. Relative to GDP* | | | | | | |
| Consumption | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 |
| Investment | 2.87 | 2.41 | 2.01 | 1.93 | 2.01 | 2.57 |
| Employment | 0.66 | 1.10 | 0.79 | 0.27 | 0.24 | 1.22 |
| Nominal E.R. | 3.33 | 1.54 | 1.16 | 1.11 | 1.21 | 1.15 |
| Real E.R. | 3.19 | 1.50 | 1.25 | 1.08 | 1.16 | 1.07 |
| Terms of trade | – | 2.27 | 2.49 | 1.79 | 1.59 | 1.74 |
| Net Exports | 0.39 | 0.31 | 0.15 | 0.06 | 0.09 | 0.38 |
| *Autocorrelations* | | | | | | |
| GDP | 0.88 | 0.66 | 0.85 | 0.81 | 0.80 | 0.60 |
| Nominal E.R. | 0.85 | 0.80 | 0.79 | 0.80 | 0.80 | 0.80 |
| Real E.R. | 0.83 | 0.80 | 0.81 | 0.80 | 0.80 | 0.79 |
| Terms of trade | – | 0.88 | 0.90 | 0.88 | 0.86 | 0.88 |
| Net Exports | 0.86 | 0.48 | 0.63 | 0.70 | 0.70 | 0.49 |
| *Cross-correlations* | | | | | | |
| Between nominal and real E.R. | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 |
| Between real exchange rates and | | | | | | |
| GDP | 0.16 | 0.47 | 0.57 | 0.62 | 0.64 | 0.41 |
| Terms of trade | – | 0.62 | 0.76 | 0.96 | 0.99 | 0.51 |
| Relative consumptions | -0.07 | 0.83 | 0.80 | 0.97 | 0.99 | 0.88 |
| Between foreign and domestic | | | | | | |
| GDP | 0.57 | 0.36 | 0.15 | 0.16 | 0.16 | 0.48 |
| Consumption | 0.37 | 0.40 | 0.38 | 0.60 | 0.54 | 0.41 |
| Investment | 0.42 | 0.44 | 0.56 | 0.41 | 0.33 | 0.46 |
| Employment | 0.44 | 0.52 | 0.10 | -0.06 | 0.47 | 0.65 |

benchmark model. As in the data, exchange rates in our model are much more volatile than the price ratio $P^*/P$ (about 7 times) and are highly correlated with each other (0.99).

In general, movements in the real exchange rate can be decomposed into deviations from the law of one price for tradable goods and movements in the relative prices of nontraded to tradable goods across countries.[22] Let $q_T$ denote the real exchange rate for tradable goods, defined as $q_T = eP_T^*/P_T$. Then, the real exchange rate can be written as $q = q_T p$, where

[22]See, for example, Engel (1999).

$p$ is a function of the relative prices of nontraded to tradable goods in the two countries.[23] Empirical evidence suggests that the all-goods $q$ and tradable-only $q_T$ real exchange rates are highly correlated and that the variability of the real exchange rate for all goods, $q$, is mostly accounted for by variability in $q_T$, when the price of tradable goods is measured using retail prices.[24] In our model, the correlation coefficient between $q$ and $q_T$ is 0.95 and the variance of $q_T$ accounts for 81 percent of the variance of $q$.[25] That is, in our model, movements in the relative price of nontraded to tradable goods play a small role in real exchange rate movements.[26] As we shall see, this finding does not imply that nontraded goods do not play an important role in the behavior of exchange rates in our model.

Nominal and real exchange rates are almost as persistent in the data (0.80 versus 0.85 and 0.83), but real GDP is less persistent than in the data (0.66 versus 0.88). The cross-correlation between exchange rates and the terms of trade is positive and consistent with the data (0.62). The cross-correlations between the real exchange rate and real GDP and the ratio of consumption across countries, however, are substantially higher than in the data (0.47 versus 0.16 and 0.83 versus -0.07).

The model implies volatilities of consumption and investment relative to real output that are broadly consistent with the data, and it implies a relative volatility of employment lower than in the data. These variables, however, display less persistence than in the data. The model implies a cross-correlation of home and foreign consumption similar to that found in the data (0.40 versus 0.37). The cross-correlation of home and foreign output is similar to that of home and foreign consumption but lower than in the data (0.36 versus

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[23] In our model $p = \left( \frac{\omega_T + (1-\omega_T)(P_N^*/P_T^*)^{1-\gamma}}{\omega_T + (1-\omega_T)(P_N/P_T)^{1-\gamma}} \right)^{\frac{1}{1-\gamma}}$.

[24] Engel (1999) and Chari, Kehoe, and McGrattan (2002) find that $q_T$ typically accounts for more than 95 percent of fluctuations in the U.S. real exchange rate. Betts and Kehoe (2004) find, using retail prices for tradable goods, that the trade-weighted average of the contribution of $q_T$ for U.S. real exchange rate fluctuations ranges between 81 percent and 93 percent, for different detrending methods. Departing from the use of retail prices for tradable goods, Betts and Kehoe (2004) and Burstein, Eichenbaum, and Rebelo (2005) find that movements in the relative price of nontraded goods may account for a large fraction of real exchange rate movements.

[25] The variance-decomposition measure we use is $var(\log q_T)/(var(\log q_T) + var(\log p))$. This measure allocates the covariance between $\log q_T$ and $\log p$ to fluctuations in $\log q_T$ in proportion to the relative size of its variance.

[26] The presence of nominal price rigidities in our model is important in this result. Assuming that prices are flexible implies that the proportion of the variance of the real exchange rate accounted for by fluctuations in the relative price of final tradable goods falls to 0.68.

0.57). The cross-correlations of home and foreign investment and employment are broadly consistent with the data. It should be noted that in our benchmark calibration all exogenous shocks are independent across countries, and thus, these positive cross-correlations reflect the endogenous transmission mechanism of shocks across countries in our model.

## 4.2 The Role of Nontraded Goods

Nontraded goods enter our model in two ways. First, households derive utility from the consumption of nontraded goods. Second, our model features a monopolistically competitive retail sector in which firms combine tradable inputs with (nontraded) retail services to produce differentiated final retail goods. In Table 2 we report statistics for our model when we eliminate retail services, nontraded consumption goods, or both. We eliminate retail services by setting the share of retail services in GDP to 0.001 while keeping the shares of trade and consumption of nontraded goods in GDP as in the benchmark model. Similarly, we eliminate nontraded consumption goods by setting the share of final nontraded consumption goods in GDP to 0.001 while maintaining the shares of trade and retail services in GDP unchanged.

The presence of nontraded goods (as nontraded consumption goods and retail services) has important implications for both exchange rate volatility and for cross-correlations of exchange rates and terms of trade with other variables in the model. Abstracting from nontraded retail services and consumption goods lowers the volatility of the real exchange rate relative to the volatility of real GDP from 1.50 to 1.16. The effects of nontraded goods on the nominal exchange rate are similar, since exchange rates are almost perfectly correlated in all alternative versions of the model. In addition, the correlation between the real exchange rate and real GDP, the terms of trade, and the ratio of consumption across countries rises as we eliminate nontraded goods.

The presence of nontraded goods matters for the adjustment to shocks to productivity in both the traded and nontraded goods sectors. To understand the role of nontraded goods in our model, we now focus on the role of these goods in the adjustment of the economy following shocks to productivity in each sector.

**Shocks to Nontraded Goods Productivity** The response of selected variables to a positive shock to productivity in the nontraded goods sector is depicted in Figure 1. In response to this shock, the price of nontraded goods falls. Absent a response of monetary policy, the price level also falls. When the monetary authority follows the interest rate rule in (11), the money stock expands, largely maintaining the price level constant in response to this shock.

Following a persistent shock to productivity in the nontraded goods sector (and the associated response of monetary policy), real GDP, consumption, and investment in the home country increase on impact and later fall gradually to their deterministic steady-state levels. Given the rise in the relative price of tradable goods, the increase in consumption is associated with a substitution toward nontraded goods and away from tradable goods. Following this shock, home consumers want to invest more in order to increase the capital stock in the nontraded sector. Investment goods, however, require the use of traded goods and nontraded goods in fixed proportions, while the country is more productive at producing nontraded goods only. Therefore, the country runs a current account deficit (and becomes a net debtor) in response to this shock.

The nominal exchange rate depreciates following the positive shock to productivity in the nontraded goods sector. This nominal depreciation is associated with an increase of the domestic terms of trade $\tau$ (defined as the relative price of domestic imports in terms of domestic exports). Absent a terms of trade movement, the demand for home and foreign inputs would increase proportionately to satisfy higher domestic investment and consumption of tradable goods. The nominal exchange rate (and terms of trade) depreciation makes domestic firms substitute domestic-produced inputs for foreign-produced goods, dampening the demand for foreign inputs and the required adjustment of foreign labor hours. The real exchange rate also depreciates following this shock. It moves closely together with the nominal exchange rate, since monetary policy ensures that price levels remain relatively constant. The presence of nontraded goods (as retail services or nontraded consumption goods) increases the share of output that benefits from a positive shock to productivity in this sector and thus magnifies the response of exchange rates relative to the response of output.

The presence of retail services and nontraded consumption goods magnifies the response of exchange rates relative to output following shocks to productivity in the nontraded goods sector while leaving the correlations of exchange rates with other variables largely unchanged. In response to shocks to productivity in the traded goods sector, however, the presence of nontraded goods affects both the magnitude of the response of exchange rates relative to output and the correlations of exchange rates with other variables in the model.

**Shocks to Traded Goods Productivity** The impulse response functions for selected variables are depicted in Figure 2. In response to a positive shock in the home country, the price of domestically produced intermediate inputs falls, while the price of nontraded goods remains largely unchanged. Therefore, the aggregate price level falls slightly.

Note that in the benchmark model, agents derive utility from the consumption of nontraded goods and final tradable goods. Final tradable goods require the use of nontraded goods and traded inputs in fixed proportions. Therefore, a persistent positive shock to productivity in the traded sector affects only the production of domestic traded inputs used in the production of consumption traded goods, and this shock has a relatively small effect on the aggregate variables of the model. Consumption, investment, and real GDP fall slightly on impact, but they rise as traded goods firms lower their prices. Since the price of home intermediate inputs falls relative to both foreign intermediate inputs (the inverse of the terms of trade) and nontraded goods, the home country's demand for intermediate inputs increases and firms in the retail sector substitute toward local inputs and away from imported inputs. Shocks to productivity in the traded goods sector imply negligible movements in exchange rates in our benchmark model.

In the absence of retail services or nontraded consumption goods, the traded goods sector takes on much greater significance and hence the effects of shocks to productivity are greatly magnified. In particular, with no nontraded goods, agents consume only an aggregate of home and foreign intermediate goods. Note that in this case the model requires a high degree of home bias (as measured by the parameter $\omega_X$) in order for it to match the calibrated import share.[27] That is, the absence of nontraded goods increases both the importance of

[27]In this case $\omega_X$ is 0.86, while it is 0.59 in the benchmark economy.

traded goods and the degree of home bias. Therefore, a productivity shock in the traded goods sector leads to significantly larger movements in aggregate variables. In particular, nominal and real exchange rates depreciate more in the absence of nontraded goods, and the role of these shocks in accounting for exchange rate volatility increases in the absence of nontraded goods. Note that as the relative importance of traded goods in the economy increases, the response of all variables (and, in particular, exchange rates) to productivity shocks increases. Therefore, the co-movement between exchange rates and other variables in the model also increases in the absence of nontraded goods.

## 4.3 The Role of Asset Markets

The business cycle properties of our model with nontraded goods are affected by the assets available to share risk across countries. In the last column of Table 2 we report statistics for our model with nontraded goods when asset markets are complete. Note that nominal and real exchange rates are less volatile relative to real GDP with complete markets than when agents are restricted to trading a riskless bond. Complete asset markets also increase the relative volatility of investment and employment relative to the benchmark model and they raise the cross-correlation between home and foreign output and employment. These differences across the two asset structures are a result of the presence of nontraded goods and the risk associated with shocks to productivity in the nontraded goods sector: In the absence of these goods the business cycle properties of the model are virtually indistinguishable across the two asset market structures.

When agents have access to a complete set of state-contingent nominal assets, the efficiency conditions for bond holdings imply that

$$\frac{u_{c,t+1}}{u_{c,t}} \frac{P_t}{P_{t+1}} = \frac{u^*_{c,t+1}}{u^*_{c,t}} \frac{e_t P^*_t}{e_{t+1} P^*_{t+1}}, \tag{14}$$

where $u_c$ denotes the marginal utility of consumption. This expression can be further simplified to

$$\frac{u^*_{c,t}}{u_{c,t}} = \kappa_0 \frac{e_t P^*_t}{P_t},$$

where $\kappa_0$ is a constant that depends on the distribution of wealth across countries in period 0.[28] This equation shows that, under complete asset markets, optimal risk sharing across countries implies that the marginal consumption value of a unit of currency is the same in both countries in all states of nature.

When agents are restricted to trade a riskless bond, as in our benchmark model, equation (14) holds only in expectation. Typically, in calibrated two-country models, the equilibrium allocation with incomplete asset markets is close to the allocation with complete asset markets. That is, agents are typically able to optimally diversify the country-specific risk they face with only one riskless bond.[29] In our model with nontraded goods, however, the business cycle properties of the model differ whether asset markets are complete or not, as the results in Table 2 show.

The major difference between the two risk sharing environments occurs in response to shocks to productivity in the nontraded goods sector and it hinges on the persistent nature of these shocks. In response to a positive and persistent productivity shock to the nontraded goods sector in the home country, the home agent wishes to consume and invest more. However, higher consumption and investment of tradable goods requires the use (in fixed proportions) of both traded intermediate inputs and nontraded goods. Since the country is more productive in nontraded goods only, the home agent borrows from the foreign agent in response to this positive productivity shock. The nominal exchange rate and the terms of trade of the home country depreciate, ensuring a substitution effect toward inputs produced in the home country and away from inputs produced in the foreign country.

The optimal risk sharing contract between home and foreign agents, however, is such that in response to a shock to productivity in the nontraded goods sector of the home country, the foreign agent works more (and substitutes hours toward the traded sector and away from the nontraded sector) and consumes less. That is, relative to the incomplete markets case, the foreign agent produces more traded goods and a smaller exchange rate depreciation is needed to equate the demand and supply of foreign traded goods. As a consequence, exchange rates

[28]See, for instance, Chari, Kehoe, and McGrattan (2002).

[29]See, for example, Baxter and Crucini (1995), Chari, Kehoe, and McGrattan (2002), and Duarte and Stockman (2005).

are less volatile, while employment is more volatile, when asset markets are complete than in the benchmark economy. In addition, employment and output are more highly correlated across countries when asset markets are complete than when they are incomplete.

### 4.4 The Role of Preferences

Chari, Kehoe, and McGrattan (2002) build a model of exchange rates driven by monetary shocks and show that the volatility of nominal and real exchange rates relative to GDP depends crucially on whether preferences are separable in consumption and leisure. In their benchmark calibration, preferences are separable, the degree of risk aversion is high, and prices are staggered and set for four quarters. This specification implies that the relative volatility of exchange rates is about 4.3. In sharp contrast, when preferences are nonseparable in their model, the standard deviations of nominal and real exchange rates relative to that of GDP are 0.07 and 0.05.

We now consider the implications of the presence of nontraded goods in our model when preferences are separable. We consider the momentary utility function

$$u\left(c, h, \frac{M}{P}\right) = \frac{1}{1-\sigma}\left\{\left(ac^{\eta} + (1-a)\left(\frac{M}{P}\right)^{\eta}\right)^{\frac{1-\sigma}{\eta}} + \exp\left\{-v(h)(1-\sigma)\right\}\right\},$$

where $v(h)$ takes the same form as before. The calibration strategy is the same as described in Section 3, and it implies that the values of $\sigma$, $a$, and $\eta$ remain the same while $\psi_0 = 2.1$ and $\psi_1 = -0.12$.

Relative standard deviations for our model with separable preferences in consumption and leisure are reported in Table 3. The mechanism that lowers exchange rate volatility with nonseparable preferences in Chari, Kehoe, and McGrattan (2002) also holds in our model driven by shocks to productivity. In our model, exchange rates are also more volatile relative to GDP when preferences are separable: 2.00 and 2.05 versus 1.54 and 1.50 with nonseparable preferences. Abstracting from nontraded goods in our model with separable preferences reduces the relative volatility of nominal and real exchange rates from 2.00 and 2.05 to 1.39 and 1.35. We conclude that the quantitative importance of nontraded goods for exchange rate variability emphasized in our benchmark specification is magnified if we

Table 3: Model results - Separable utility

| Statistic | Benchmark Economy | No Retail | No $C_{NT}$ | No NT |
|---|---|---|---|---|
| *Stand. Dev. Relative to GDP* | | | | |
| Consumption | 0.64 | 0.64 | 0.64 | 0.64 |
| Investment | 1.91 | 1.65 | 1.69 | 1.81 |
| Employment | 0.68 | 0.68 | 0.42 | 0.35 |
| Nominal E.R. | 2.00 | 1.26 | 1.22 | 1.39 |
| Real E.R. | 2.05 | 1.36 | 1.21 | 1.35 |
| Terms of trade | 3.74 | 3.14 | 2.10 | 1.84 |
| Net exports | 0.11 | 0.06 | 0.04 | 0.05 |

consider separable preferences in consumption and leisure.

# 5 Alternative Price Setting Mechanisms

The importance of fluctuations in the relative price of tradable goods across countries in understanding real exchange rate fluctuations has generated an extensive debate on the nature of the international pricing decisions of firms. Most of the literature has focused on the implications of two extreme alternative pricing mechanisms: producer currency pricing (PCP) and local currency pricing (LCP). With PCP, as in our benchmark model, the law of one price for traded goods always holds and, thus, the price in local currency of imported goods moves one-to-one with the nominal exchange rate. In this case, a depreciation of the currency makes foreign goods more expensive relative to domestic goods (the terms of trade depreciates) and generates a redirection of world expenditure toward domestic goods (expenditure switching effect of exchange rate changes). In contrast, with LCP, firms are able to price discriminate across markets and set prices in the currency of the buyer. In the presence of nominal price rigidities, the price in local currency of imported goods does not respond to unanticipated movements of the nominal exchange rate and the law of one price fails. In this case, a nominal depreciation does not affect prices that consumers face and does not generate an expenditure switching effect in the short run. The empirical evidence on the slow pass-through of exchange rate changes to consumer prices and substantial deviations from the law of one price suggest that prices of imported goods are sticky in the currency of the buyer. However, as Obstfeld and Rogoff (2000b) argue, the LCP assumption is not consistent with empirical evidence supporting the expenditure switching effect of exchange rate changes in the short run.[30]

In this section we disentangle the implications of these two alternative pricing mechanisms for the properties of our model. We find that our model behaves quite similarly whether intermediate goods producers discriminate across markets and set their prices in the currency of the buyer or whether they set a common price for both markets in the currency of the seller. In particular, in our model, the properties of the real exchange rate and the relative international price of final tradable consumption goods are not affected substantially by the pricing assumptions of intermediate goods producers. However, with PCP the correlation between the nominal exchange rate and the terms of trade is highly positive and consistent with the data, while with LCP this correlation is positive but substantially lower.

## 5.1 Price Setting under Alternative Pricing Mechanisms

Our benchmark price-setting specification is producer currency pricing. Under this arrangement, the (log-linearized) price of the home intermediate traded good chosen in period $t$ is given by

$$\widetilde{p}_{h,t}(0) = \mathrm{E}_t \left[ \sum_{j=0}^{J_h-1} \rho_j \left( \widetilde{\psi}_{h,t+j} + \widetilde{P}_{t+j} \right) \right], \tag{15}$$

where a "~" over a variable indicates the log-linearization of the variable around its steady state value and $\rho_j$ is a function of $\beta$.[31] Equation (15) is derived from the first-order condition of problem (9) in section 2, and we have linearized around a zero inflation steady state. Notice that variables that scale the level of demand do not enter equation (15) because, to a first-order approximation around the optimal price, they influence marginal cost and marginal revenue to the same extent.

Under local currency pricing, producers of intermediate traded goods are able to discrim-

[30] Obstfeld and Rogoff (2000b) present empirical evidence suggesting that nominal exchange rates and the terms of trade are positively correlated.

[31] In particular, $\rho_j = \beta^j / \left( \sum_{j=0}^{J_h-1} \beta^j \right)$. For $\beta$ close to one, $\rho_j \approx 1/J_h$.

inate across markets and separately solve for the optimal price in the currency of the buyer in each market. The (log-linearized) pricing equations for the prices chosen in period $t$ of the home traded good at home and abroad are given by,

$$\widetilde{p}_{h,t}(0) = \mathrm{E}_t \left[ \sum_{j=0}^{J_h - 1} \rho_j \left( \widetilde{\psi}_{h,t+j} + \widetilde{P}_{t+j} \right) \right], \tag{16}$$

and

$$\widetilde{p}^{*}_{h,t}(0) = \mathrm{E}_t \left[ \sum_{j=0}^{J_h - 1} \rho_j \left( \widetilde{\psi}_{h,t+j} + \widetilde{P}_{t+j} - \widetilde{e}_{t+j} \right) \right], \tag{17}$$

respectively. First, note that the pricing equation for the home traded good sold domestically is the same under both mechanisms (equations 15 and 16). Second, note that with LCP, the law of one price holds for newly priced goods (i.e., $\widetilde{p}^{*}_{h,t}(0) = \widetilde{p}_{h,t}(0) - \widetilde{e}_t$) when the exchange rate follows a random walk (equations 16 and 17).

Since the behavior of the exchange rate in our model with LCP is close to a random walk (as in the benchmark model), it follows that the law of one price holds approximately for newly priced goods. Therefore, differences across the two price setting mechanisms following an exogenous shock can only arise from differences in the relative price across countries of prices that are preset. However, as additional vintages of firms reset their prices after a shock, the distinction between the two price setting mechanisms disappears. Thus, any potential differences are short lived, and because the differences are transitory, they should not affect variables such as investment or consumption to a great degree.

## 5.2 Implications of PCP versus LCP

We now compare the implications of the two alternative pricing assumptions for producers of traded inputs. We first look at the responses of selected variables to shocks to productivity in the traded and nontraded goods sector under the two alternative pricing mechanisms displayed in Figures 3 and 4. These responses are almost indistinguishable between the two pricing mechanisms, except for the response of the terms of trade and the price of imports to a shock in the nontraded goods sector.

In response to a shock to productivity in the traded goods sector, the behavior of all variables is not influenced substantially by the different pricing arrangements. As Figure 3 shows, the response of the nominal exchange rate to this shock is small in both cases. As a result, under LCP, unanticipated shocks to productivity in the traded goods sector do not generate large deviations from the law of one price, even for traded inputs whose price is preset. Therefore, the response of all variables is similar across the two pricing mechanisms.

In response to a shock to productivity in the nontraded goods sector, the behavior of the terms of trade, the price of imports, and (to a lesser extent) the price of the traded composite $X_T$ differs markedly across the two pricing arrangements. In contrast, the nominal exchange rate, output, and the price level behave very similarly. One underlying reason for this difference across these two sets of variables is that trade is a small portion of the economy: Although the response of import prices differs between PCP and LCP, this difference diminishes as prices are aggregated up to the consumer price level. In fact, there is not a substantial difference even in the behavior of the price of the intermediate composite traded good $P_X$ under the different pricing systems. Another reason why the two pricing mechanisms lead to similar behavior of the nominal exchange rate, output, and the price level is that, as discussed before, price setters respond much the same way under LCP as they do under PCP. Thus, any difference between the two mechanisms follows from the existence of preset prices. However, as successive vintages of firms reset their prices, the behavior of the price of imports across the different pricing mechanisms converges.

The most noticeable difference across pricing mechanisms is the behavior of the terms of trade and the price of imports in response to the nontraded goods technology shock. An increase in technology in the nontraded goods sector leads to a depreciation of the nominal exchange rate. With PCP, the price in local currency of the imported composite good $P_f$ rises by more than the exchange rate: The newly reset prices of imported goods rise (in foreign currency) in response to the increase in domestic demand and all prices of imported goods (newly reset and preset) move one-for-one (in local currency) with the exchange rate. The newly reset price (in domestic currency) of exports rises as domestic firms re-adjust their prices, due to higher domestic wages, but less so than the exchange rate. As a result, this shock depreciates the currency and raises the price of imports relative to exports in the short run. Under LCP, preset prices of imported goods are not affected by movements in the exchange rate, and the domestic-currency price of domestic exports rises with the nominal exchange rate. Thus, on impact, the depreciation of the nominal exchange rate lowers the price of imported goods relative to exports. However, as additional vintages of firms adjust their prices, the pricing effect dominates and the terms of trade eventually depreciates.

The impulse response functions in Figures 3 and 4 suggest that the properties of the variables in the model, other than the terms of trade and price of imports, are approximately the same across the two pricing systems. However, we expect the correlations of the terms of trade and the price of imports with other variables to differ. This is indeed the case. The relative volatilities of various variables are not affected substantially by the pricing mechanism. For example, the standard deviations of output, the real exchange rate, the tradable-only real exchange rate, and the terms of trade under PCP relative to those under LCP are 0.95, 1.06, 1.04, and 1.03. Similarly, the model also implies similar persistence across pricing mechanisms. In particular, the autocorrelation coefficients for these same variables are 0.66, 0.80, 0.68, and 0.88 under PCP, while they are 0.65, 0.81, 0.71, and 0.88 under LCP.

In contrast, the cross-correlations of the terms of trade and the price of imports with other variables differ substantially across the two pricing assumptions. In Table 4 we report the correlation coefficients between selected variables under the two alternative systems.

Table 4: Model Correlations

| *Cross-correlations* | PCP | LCP |
|---|---|---|
| Between terms of trade and | | |
| output | 0.48 | 0.27 |
| nominal ex. rate | 0.51 | 0.11 |
| real ex. rate | 0.63 | 0.26 |
| price of imports | 0.80 | 0.73 |
| Between price of imports and | | |
| output | 0.38 | 0.25 |
| nominal ex. rate | 0.71 | 0.48 |
| real ex. rate | 0.77 | 0.58 |
| Between output and real e.r. | 0.47 | 0.40 |

The model implies higher cross-correlations of the terms of trade and the price of imports with other variables under PCP. In particular, the correlation coefficient between the terms of trade and the nominal exchange rate is 0.51 with PCP and 0.11 with LCP. Data for Canada, the U.K., Germany, Italy, France, and the U.S. suggest that the comparable correlation ranges from 0.34 for Canada to 0.70 for Germany and averages 0.47.[32] Thus, the PCP model is closer in line with the data regarding the correlation between the terms of trade and exchange rates.

# 6 Conclusion

In this paper, we argue that nontraded goods play an important role in accounting for real exchange rate fluctuations. Our quantitative study suggests that nontraded goods improve the implications of our model compared to the model without either consumption of non-traded goods or nontraded retail services, while fluctuations in the relative price of nontraded goods account for a small fraction of real exchange rate fluctuations.

Given the work of Stockman and Tesar (1995), and the importance of nontraded goods in the economy, this analysis is a natural extension to existing work in open economy models. The overriding message is that nontraded goods serve a useful role in bringing the model closer to the data. The presence of nontraded goods magnifies the volatility of the real and nominal exchange rate relative to GDP. Importantly, the increase in the volatility of the real exchange rate is due largely to increased volatility in tradable goods prices rather than increased volatility in the relative price of nontraded goods across countries. Further, the presence of nontraded goods reduces the correlation of the real exchange rate with other variables and it improves the cross-country correlations implied by the model. Our benchmark model, however, is still at odds with the very low and often negative correlations between real exchange rates and relative consumptions across countries that are found in the data.

[32]The data used are the relative price of imports to exports and the trade-weighted nominal exchange rate, obtained from the Bank of England's website.

# A Data

The data series for U.S. GDP, consumption, investment, and net exports are obtained from the OECD Quarterly National Accounts (QNA). They are, respectively, Gross Domestic Product, Private Final Consumption Expenditures plus Government Final Consumption Expenditures, Gross Fixed Capital Formation, and Exports minus Imports of Goods and Services. All series are measured at fixed constant prices. The data series for U.S. employment is the Civilian Employment Index from the OECD Main Economic Indicators (MEI).

The series for the U.S. nominal and real exchange rates are the Nominal and Price-Adjusted Major Currencies Dollar Indices published by the Federal Reserve Board.

For GDP, consumption, and investment in the rest of the world, we constructed an aggregate of Canada, Japan, and 15 European countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Norway, the Netherlands, Portugal, Spain, Sweden, and the UK). The data used are from OECD QNA for Canada, Japan, and EU15. The data are measured at fixed constant prices, and they are aggregated using PPP exchange rates. The data series for employment in the rest of the world are constructed from Civilian Employment Indices for Canada, Japan, and eight European countries from the OECD MEI (Comparative Subject Tables). These data are aggregated using population weights.

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Figure 1: Benchmark Economy - positive shock to $z_N$

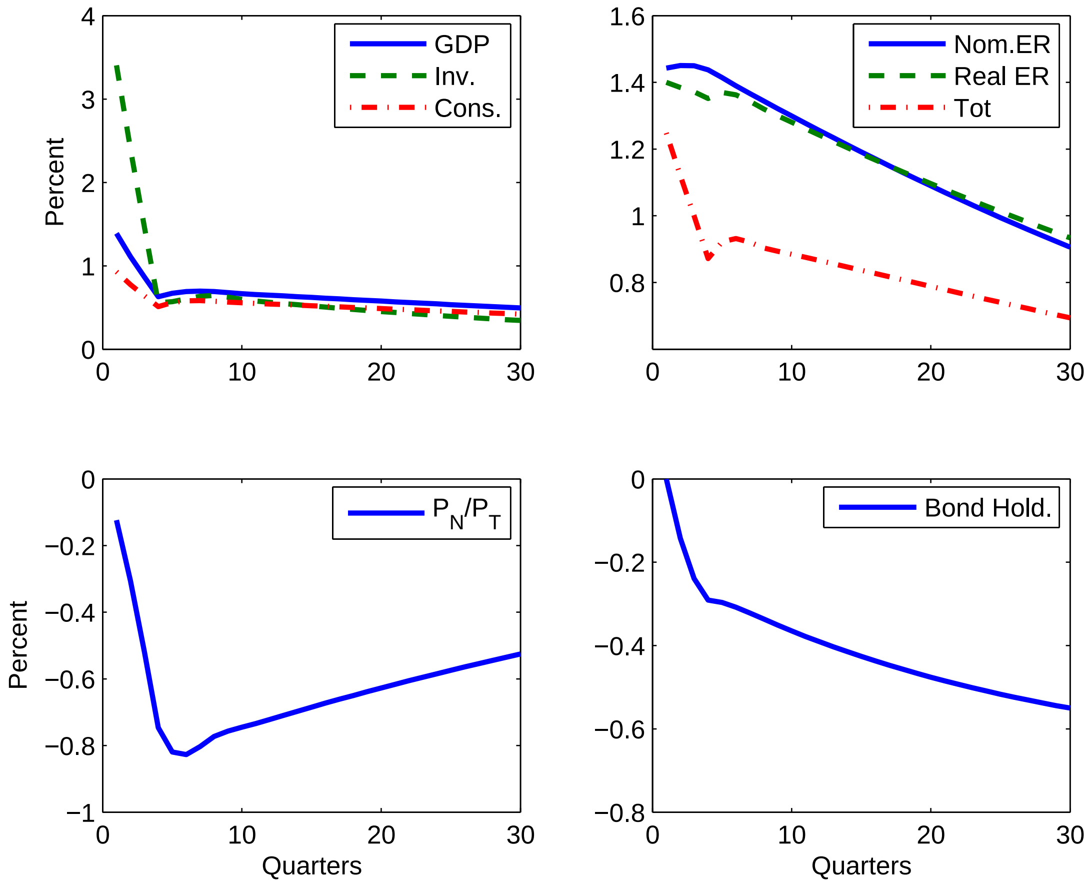

Figure 2: Benchmark Economy - positive shock to $z_T$

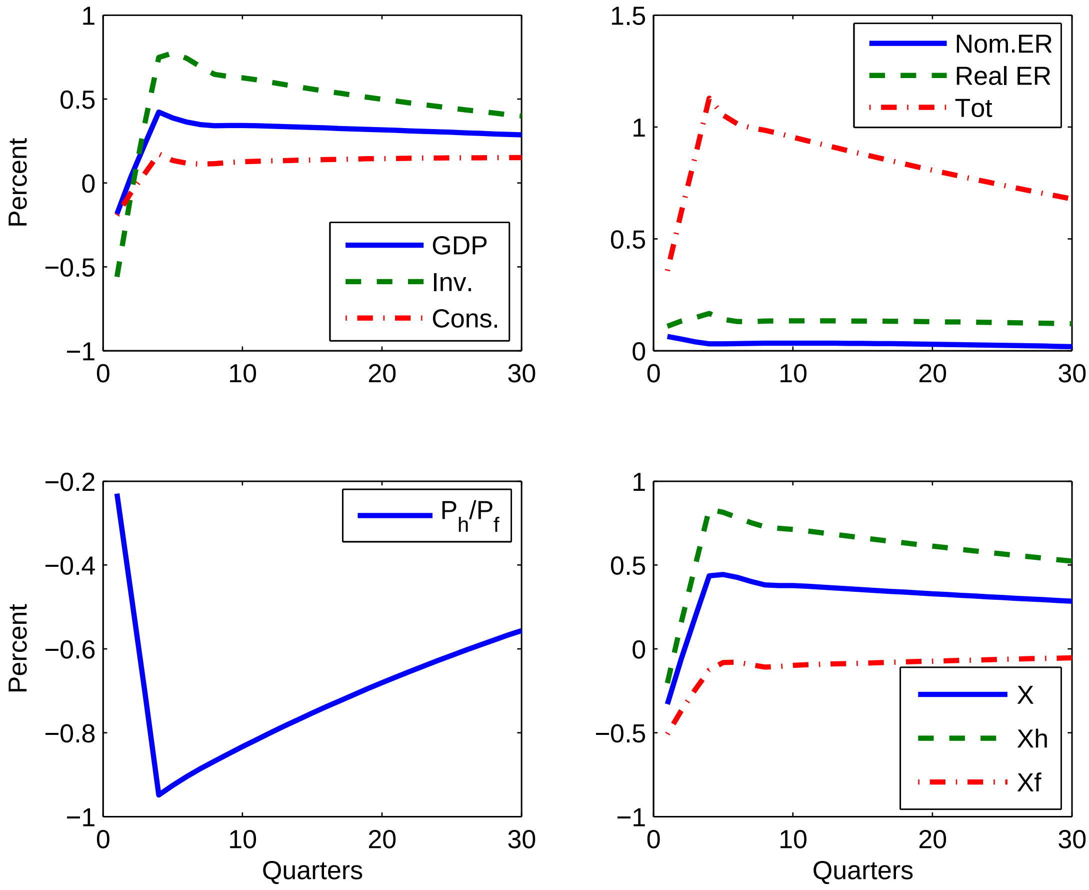

Figure 3: PCP versus LCP - positive shock to $z_T$

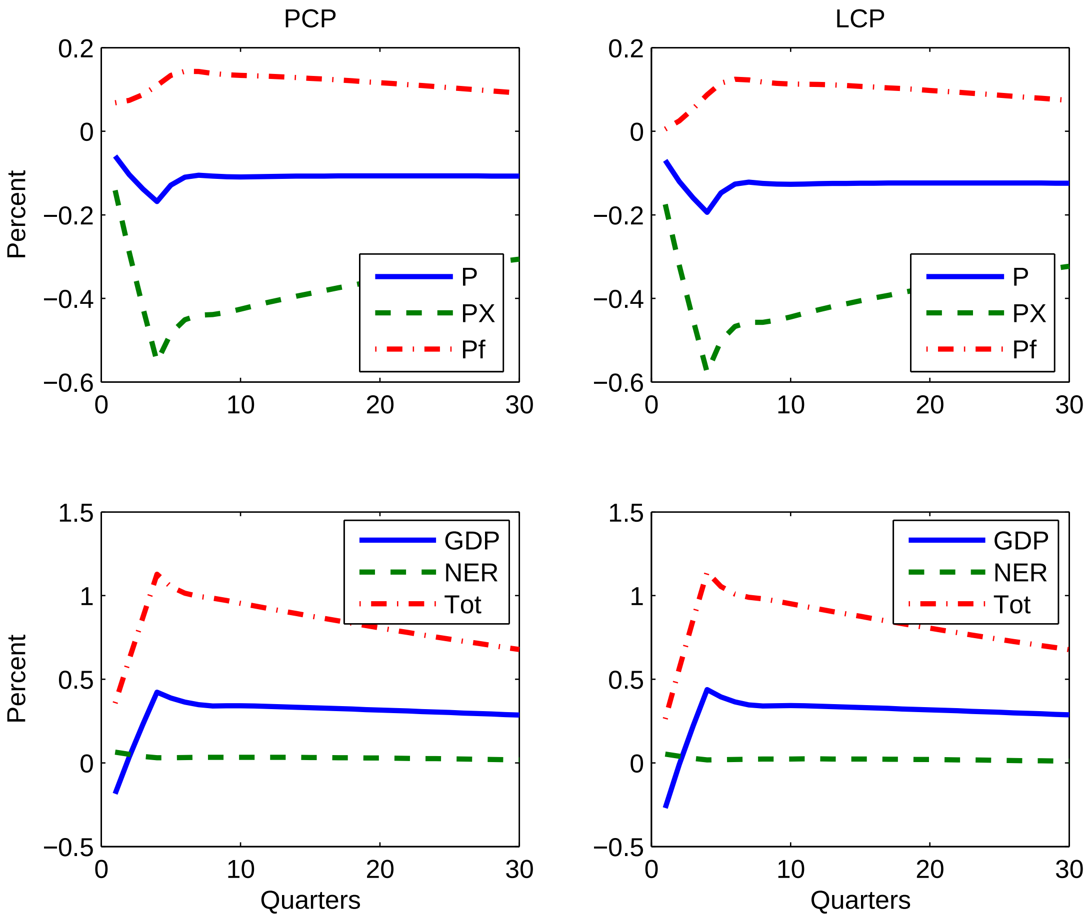

Figure 4: PCP versus LCP - positive shock to $z_N$